

Influence of Sensory Dependence on Postural Control

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Influence of Sensory Dependence on Postural Control

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The current project is part of an NSBRI funded project, “Development of Countermeasures to Aid Functional Egress from the Crew Exploration Vehicle Following Long-Duration Spaceflight.” The development of this countermeasure is based on the use of imperceptible levels of electrical stimulation to the balance organs of the inner ear to assist and enhance the response of a person’s sensorimotor function. These countermeasures could be used to increase an astronaut’s re-adaptation rate to Earth’s gravity following long-duration space flight. The focus of my project is to evaluate and examine the correlation of sensory preferences for vision and vestibular systems. Disruption of the sensorimotor functions following space flight affects posture, locomotion and spatial orientation tasks in astronauts. The Group Embedded Figures Test (GEFT), the Rod and Frame Test (RFT) and the Computerized Dynamic Posturography Test (CDP) are measurements used to examine subjects’ visual and vestibular sensory preferences. The analysis of data from these tasks will assist in relating the visual dependence measures recognized in the GEFT and RFT with vestibular dependence measures recognized in the stability measures obtained during CDP. Studying the impact of sensory dependence on the performance in varied tasks will help in the development of targeted countermeasures to help astronauts readapt to gravitational changes after long duration space flight.

NOMENCLATURE

AP	=	Anterior-Posterior
CDP	=	Computerized Dynamic Posturography
COM	=	Center of Mass
COP	=	Center of Pressure
CPHS	=	Committee for the Protection of Human Subjects
EQ	=	Equilibrium Score
GEFT	=	Group Embedded Figures Test
HM	=	Head Movement
HSTF	=	Human Subject Test Facility
JSC	=	Johnson Space Center
ML	=	Medial-Lateral
NASA	=	National Aeronautics and Space Administration
NHM	=	No Head Movement
RFT	=	Rod and Frame Test
SOT	=	Sensory Organization Test

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I. INTRODUCTION

Astronauts returning from spaceflight exhibit sensorimotor disturbances affecting posture, locomotion and spatial orientation functions. Humans sense position and motion in three-dimensional space through the interaction of proprioceptors, vision and the vestibular system. The vestibular system enables an individual to determine body orientation, sense of direction and speed of movement and balance control. Absent visual inputs, commonly experienced in spaceflight, enables the astronauts to utilize their vestibular system more often [1]. However, when exposed to micro-gravity environment ones vestibular system is confined with conflicting information that may result in motion sickness, dizziness and disorientation. In order for astronauts to adapt faster to gravitational changes, it is important to understand the contribution of neurosensory changes associated with spaceflight [2]. The main goal is to study the impact of sensory dependence on the performance of these varied tasks in order to aide in the development of targeted countermeasures to help astronauts readapt to gravitational changes after long duration space flight.

The brain utilizes vestibular inputs as an internal reference system for orientation about which adaptive changes in proprioceptive and visual inputs are made [3]. In order to address this measure the CDP was used to evaluate the vestibular contributions in subjects. CDP is a quantitative method for isolating and assessing how the balance system uses individual sensory and motor components of balance in the standing human [3]. Maintaining the Romberg position (eyes-closed stance) on a level fixed surface, subjects use primarily proprioceptive sensory cues, which signal body motion relative to feet, but if the surface is moving, subjects discount the proprioceptive information and shift toward reliance on graviceptive information. Essentially, the postural control system is utilized to dynamically regulate its source of sensory information [6].

Visual preference is evaluated in terms of perceptually dependent or independent. A key component of this concept is the ability to utilize visual sensory information in perceptual tasks emphasized in the performance of the GEFT and RFT [4]. The GEFT performance relies heavily on the competence of identifying simple figures in perceptual tests, while the RFT incorporated the adjustment of a luminous rod inside a tilted frame to an individual's ideal sense of vertical [4, 5]. The GEFT and RFT performance are used as markers for the visual preference evaluation. It is hypothesized

that both measures should have a correlation based on the findings that the individual who takes a longer amount of time to discover the simple figure in the complex GEFT design is also likely to tilt the rod farther from ideal sense of vertical [4].

Essentially, the correlation of these sensory preferences in utilizing visuo-vestibular cues will be examined. The analysis of data from these tasks will assist in relating the visual dependence measures recognized in the GEFT and RFT with vestibular dependence measures recognized in the stability measures obtained during CDP. Furthermore, it is anticipated to determine if visual preference is indeed influenced by vestibular performance. In addition, examine how the vestibular performance plays a role in the SOT transition from a sway-referenced surface to a fixed support to develop some form of adaptation.

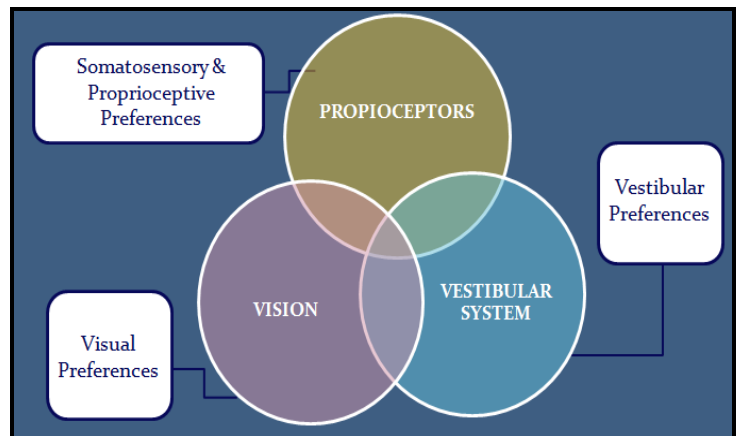


Figure 1. Sensorimotor System.
Individual Preferences exist with perturbed senses.

II. MATERIALS & METHODS

A. Subjects

The study involved nine adult human subjects (5 males, 4 females; age range 23-50 years) for a verification of the protocol. All participants had no history of balance or vestibular abnormalities except for two, however were categorized to be in good status to perform this study at minimal risk level.

B. Procedures

1. Computerized Dynamic Posturography (CDP)

Balance performance was measured using the CDP system (EquiTest® System, NeuroCom International, Clackamas, OR). In order to analyze how the subjects enhance their vestibular performance, six of the nine participants were subjected to six 90 second trials with absent vision (eyes closed), and dynamically altered somatosensory reference information using EquiTest Sensory Organization Tests. The foot support was either fixed (SOT2) or sway-referenced by rotating the force platform in the sagittal plane in direct proportion to the estimated instantaneous center-of-mass (COM) sway angle (SOT5). Throughout each trial the subject is instructed to adhere to the Romberg position, maintaining a stable upright posture with arms crossed at the chest, and eyes closed (Fig. 2).

External auditory orientation cues were masked by white noise supplied through headphones. The study involves a set of static and dynamic head tilt conditions. During static head tilt trials, subjects are instructed to maintain head erect (0°). Dynamic head tilt trials involved subjects attempting to perform continuous $\pm 20^\circ$ sinusoidal head oscillations paced by an audible tone, transmitted through headphones at a frequency of 0.33Hz. Test operator and a spotter monitored the performance of the subject assuring if a fall (a lean too forward and/or backward, rising of the heels and/or metatarsals) is presented the subject is safe, apart from being supported by a harness.

Prior to testing, the operator collected the subject's heel to ankle length. These measurements allow for the subject to be positioned on the platform in order for the plate movements to be enabled about the subject's ankles. The monitoring of the posture performance was measured using center-of-mass sway angles were estimated from AP and medial-lateral (ML) center-of-force positions, which were computed from force transducers mounted within the EquiTest force plates. The postural performance was defined by the Equilibrium Score (EQ) derived from the peak to peak anterior- posterior (AP) sway angle (θ) of the center of pressure (COP).

The computational equation used to calculate the EQ score is represented by the following:

$$\text{EQ} = \frac{100}{1 + 12.5^\circ \theta} \quad [1]$$

where 12.5° is the maximum theoretical peak-to-peak sway in the sagittal plane. Thus, EQ scores would vary from 100 indicating little to no sway to zero which indicates inability to maintain equilibrium.



Figure 2. SOT2 on the CDP.

SOT2 demonstration with arms crossed at the chest and eyes closed maintaining an upright stable posture.

2. Group Embedded Figures Test (GEFT)

The GEFT was used to measure the perceptual performance in disembedding simple shapes. The test involves a booklet with a series of complex patterns and the subjects' ability to locate a simple form when it is hidden within a complex pattern (Fig.3). The subjects were instructed to only trace one form of the specified shape per problem and to maintain the same size, proportion and direction. GEFT consist of three sections (26 items), first section serves as a practice for familiarization of the guidelines timed for two minutes and last two sections are combined scored (0-18) and timed five minutes each. A separate sheet displaying the simple forms is provided to the subject for a better ease of taking the test.

The GEFT performance is evaluated based on the GEFT Manual by Witkin, Oltman, Raskin and Karp. The GEFT score is the total number of the simple forms traced correctly in the combined second and third section [5]. The first section is used as means of familiarization of the subject to the directions given by the operator and allows for the operator to determine if the needs to be reinforced with more helpful directions. In addition, the time taken by subject to complete test was recorded as an additional measure of GEFT performance.

3. Rod and Frame Test (RFT)

The ability to correctly identify true vertical when presented with conflicting visual information was measured using the computerized RFT system (LabVIEW Instrument). The apparatus consisted of a rectangular tunnel (0.6m long, 30x30 cm section) made of foam boards, which acts as a visual frame of reference and can be tilted to the right or the by specific amount using a digital inclinometer [7]. At the closed end of the frame is positioned a computer monitor displaying the luminous rod in a high-resolution graphic mode (0.1°). At the opposite side of the tunnel which fills the entire field of vision during the testing, subject sat 0.6m from the screen and maintained an upright position in the chair (adjustable with height) with their chin resting on a foam cube in front of the frame and operated a remote control to manually define their sense of true vertical of the computerized rod presented on the monitor screen. The test consisted of eight trials with the rod and frame tilted $\pm 18^\circ$ (positive to the Left and negative to the Right) in the following sequence: Frame: L,L,L,L,R,R,R,R; Rod: L,R,R,L,L,R,R,L [7]. During the reconfiguration of the frame, the subject closed their eyes to eliminate any form of visual

frame of reference. Before each rod display and setting, a fixation point appeared in the center of the screen followed by a white screen [7]. The RFT performance is the quantified deviation of the final rod angle from the absolute vertical and completion time.

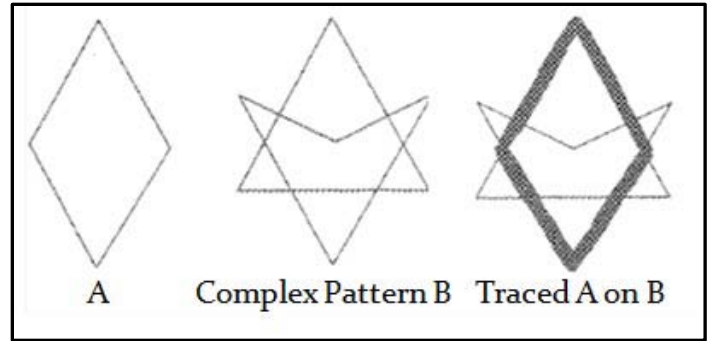


Figure 3. Group Embedded Figures Test
Example GEFT Process.



Figure4. Rod and Frame Test Apparatus.
Demonstration of maintaining an upright position in the chair with chin resting on a foam cube in front of the frame and operating remote control.

III. RESULTS

A. Equilibrium Score Performance

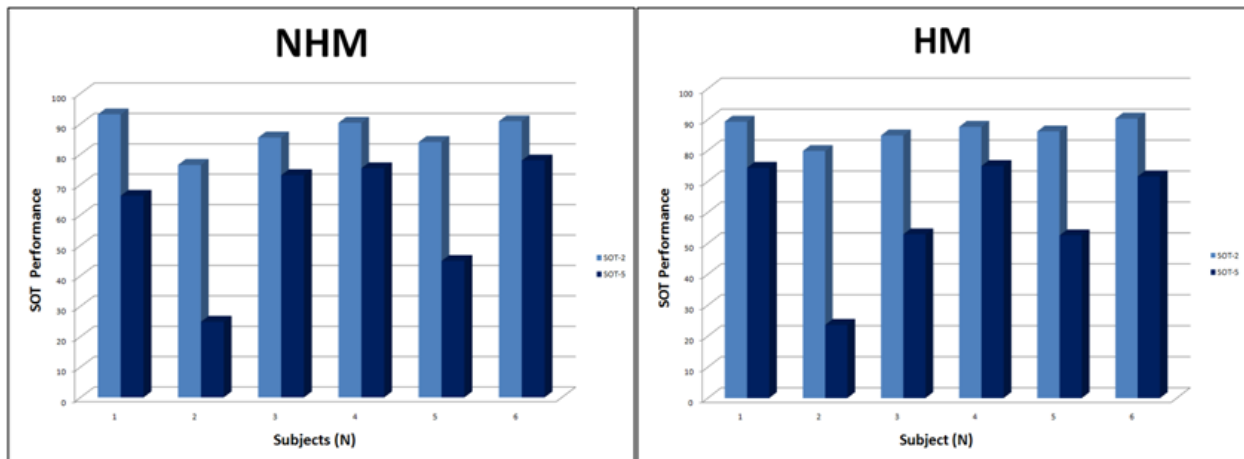
The median EQ score for each subject were calculated for the static and dynamic head tilt conditions and displayed no distinct difference between the two head positions. The average standard deviations for each subject increased with dynamic tilts and showed variation within the means. To understand the subjects' performance in the SOT5 stage, we compared the EQ scores in reference to the pre-SOT2 stage or baseline (average range 80-94).

The sway reference performance is compared to the baseline for the two conditions. The sway performance increases and/or decreases with static and dynamic head tilts. Figure 5(a,b) highlights the sway performance during static (NHM) and dynamic (HM) head tilts for all six subjects. The y-axis represents the SOT performance. Significantly, most subjects maintained a constant sway reference performance, showing light differences between NHM and HM stages. Subject two displays a 60% decrease in sway reference performance from in both NHM and HM conditions, while subject three

displays a 15% decrease in performance in NHM and a 30% decrease in HM. The HM trials served to narrow the performance spectrum for those who are not challenged during the NHM trials. It is expected that the HM trials would decrease the sway performance in most subjects since it is more provocative.

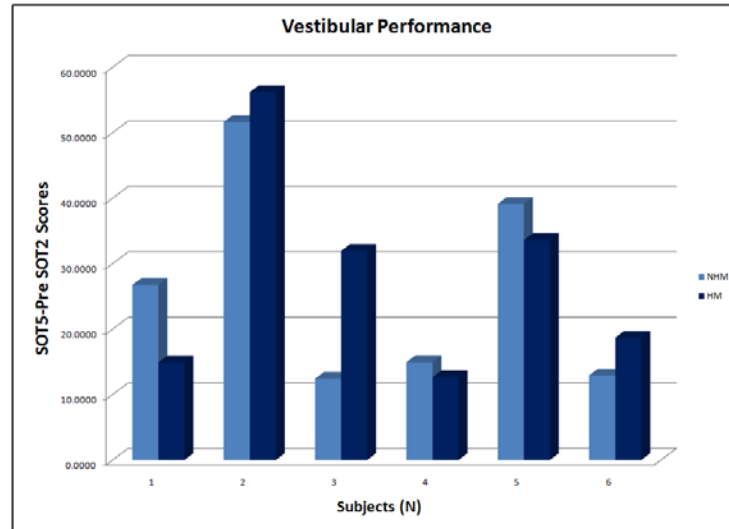
Figure 5(b) illustrates the vestibular performance or the normalized change of SOT5 and pre-SOT2 in the NHM and HM trials. Adequate vestibular performance, where an individual is able to control their balance is illustrated by a small change from pre-SOT2 to SOT5. Significantly the vestibular performance correlates with Figure 5(a), that being if the sway reference performance decreases in comparison to the norm, thus a decrease in vestibular utilization. Subject three displays a constant change for the NHM and HM conditions, while subject 4 displayed a lower constant lower change in the EQ score from pre-SOT2 to SOT5.

Sway Reference Performance



(a)

(b)



(c)

Figure 5. Percent EQ performance to baseline.

(a) Sway Reference Performance in NHM (b) Sway Reference Performance in HM (c) Vestibular Performance. NHM (light blue) represents the no head movement and HM (dark blue) represents the head movement trials, $N=6$.

B. Visual Preference Performance

1. GEFT

The mean and standard deviation were calculated to obtain the standard error of the mean ($SEM=0.69$). The total time given to the subjects to complete the test was 10 minutes (2, 5 minute sections). Figure 6(a) displays the GEFT performance in terms of the computed total score and completion time. It is hypothesized that an increase in the length of time taken to complete the test, reflects that the individual is more visually dependent [5]. There is no distinct correlation with the GEFT score to the completed time; however the average score computed is 18 with varying time.

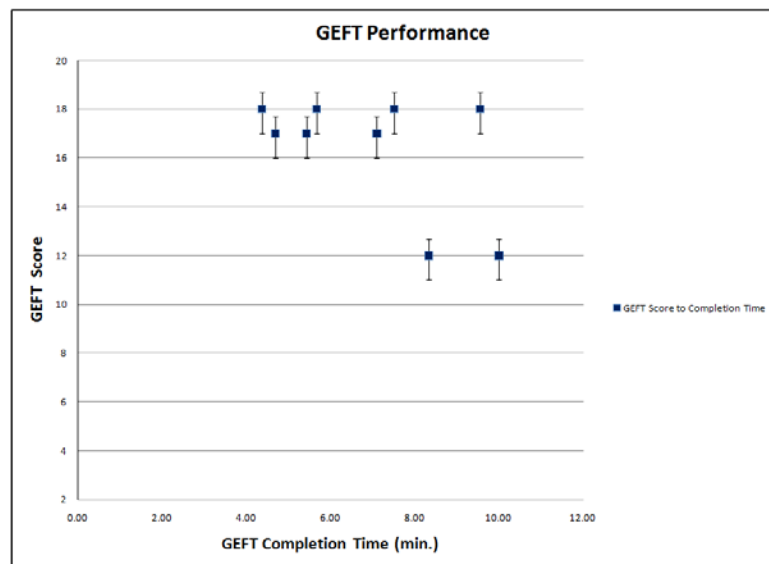


Figure 6. Group Embedded Figures Test Performance.

GEFT Performance, error bars represent the standard error of the mean. The average GEFT score is 18 with varying time, $N=9$.

2. RFT

The absolute average deviation the RFT performance was calculated from the eight trials, as well as the average completion time. Figure 7 illustrates the RFT performance and it was hypothesized that with an increase in time the perception of the rod reflected by the final angle would increase as well. However, Fig. 7 displays no distinct correlation with the rod angle and completed time. The average completion time of the sample size ($N=9$) is 20 seconds with varying rod angles

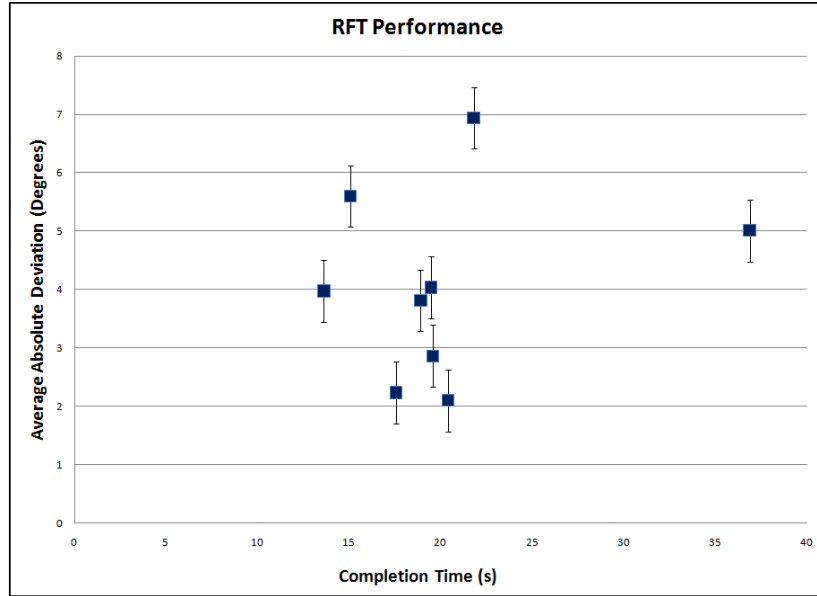


Figure 7. Rod and Frame Test Performance.

The errors bars represent the standard error of the mean, $N=9$.

3. GEFT and RFT Correlations

The GEFT and RFT both serve as methods to measure visual preference. The idea behind visual preference is the ability to utilize visuo-vestibular cues to perform a specific task [4]. The RFT measures an individual's perception of true vertical; while GEFT measures visual perception by means of applying disembedding skills. Thus, GEFT though a test of visual preference, does not take in account the visuo-vestibular sensory integration as well as the RFT [4]. It is clear that GEFT and RFT may contribute different aspects of visual preference by the negative linear relationship ($r^a=0.39$) of the completed times represented in Fig 8(a). Moreover, taking in to account the absolute average deviation as a dominant measure of visual preference and the completion time of performing the GEFT (Fig. 8(b)) significantly displays no correlation ($r^a=0.06$). Thus, confirming that RFT and GEFT measure different skills within the ability to use visual information.

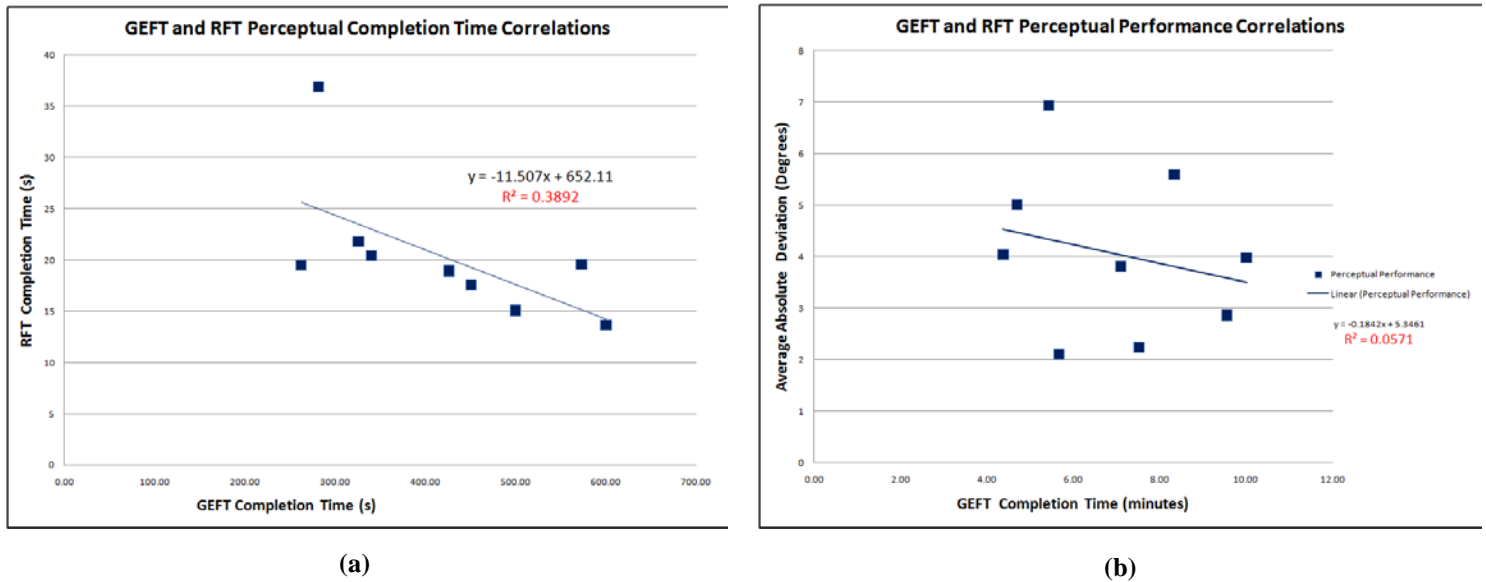


Figure 8. GEFT and RFT Correlations.

(a) GEFT and RFT time correlations in seconds (b) Absolute RFT average performance and GEFT time correlations. Graph (a) displays a negative linear relation ($r^2 = 0.39$), (b) displays no correlation ($r^2 = 0.06$).

C. Visuo-Vestibular Performance

The NHM and HM trial were assessed from CDP and RFT in terms of the vestibular performance versus the absolute average RFT performance. These forms of measures correspond to relevant sensory information which triggers the use of visuo-vestibular sensory integration. Figure 9 displays the correlation between vestibular and visual performance, highlighting a clear positive power relation ($r^2 = 0.58$) with the NHM trials only. Significantly, Fig.9 illustrates that with increasing visual dependence, there is a decrease in vestibular utilization (increase in the change of sway to recovery performance). Thus, more recovery or work is required to maintain balance and vice versa. Essentially, the results correspond to what was hypothesized, that being vestibular performance is inversely related to visual preference. However, HM trials did not display a clear correlation ($r^2 = 0.03$) of the visuo-vestibular sensory integration, thus more factors should be taken into account.

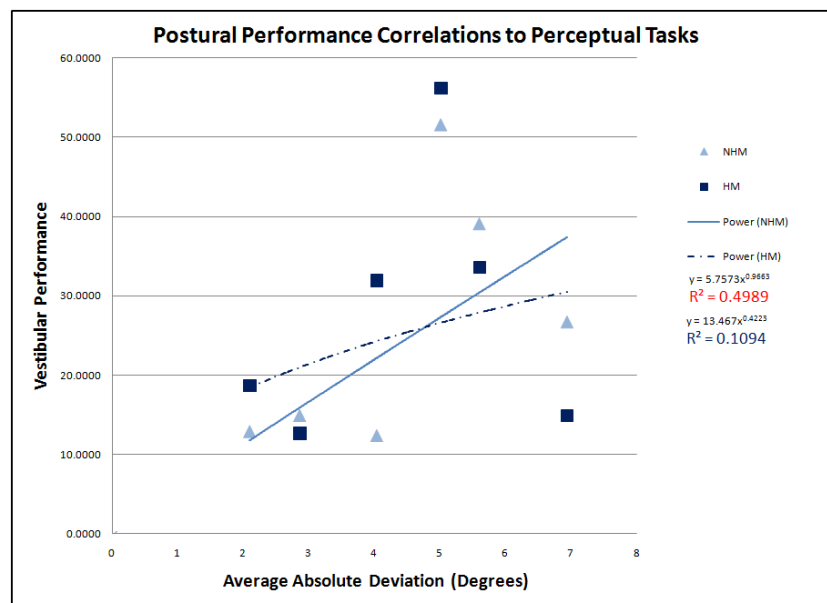


Figure 9. CDP and RFT Correlations.

NHM (\blacktriangle) displays a power relation between vestibular and visual performance ($r^2 = 0.50$). HM (\blacksquare) does not demonstrate a correlation ($r^2 = 0.10$).

IV. CONCLUSIONS

The overall goal is to study the human sensory preference to increase efficacy of countermeasures based on the use of imperceptible levels of electrical stimulation to the balance organs of the inner ear to assist and enhance the response of a person's sensorimotor function during gravitational transitions allowing rapid vehicle egress. Essentially, GEFT and RFT display different characteristics of visual preference when incorporating visuo-vestibular sensory utilization. Furthermore, the degree of vestibular performance influences the adaptation state when a disturbance is encountered enabling an individual to for example increase their vestibular utilization for postural control. Thus, individuals with the need to increase their utilization of vestibular cues are perceptually dependent and rely heavily on vision. With that in mind, further analysis will need to be taken in account such as path length of the stabilogram, rotational degrees (roll, pitch, and yaw), and velocity, acceleration of body sway to gain more statistical understanding of visuo-vestibular sensory integration.

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